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Executive Summary

NOAA is making major contributions to the solar forecasting project in three areas. First, it is improving its forecasts of solar irradiance, clouds, and aerosols in its numerical weather prediction models. Second, it is providing advanced satellite products for DOE's FOA awardees to use in their forecast systems. Third, it is using high-quality ground-based measurements from SURFRAD and ISIS stations to verify and validate forecast model output. This reports covers results from all three areas for the period May 1, 2014 – April 30, 2015.

Modeling

In its modeling effort, NOAA continues work to improve the skill of solar forecasts from the Earth System Research Lab (ESRL) research versions of the 13-km Rapid Refresh (RAP) and the 3-km High-Resolution Rapid Refresh (HRRR) models, which are in turn transitioned into operations at the National Centers for Environmental Prediction (NCEP). A major milestone was achieved in September 2014 with the initial operational implementation of the HRRR at NCEP.

In the ESRL research versions of the models, testing and development, in both real-time runs and retrospective experiments, is guided by an extensive in-house verification system. Early in the SFIP project, we developed the capability to verify our model forecasts against the high-quality surface radiation measurements from the SURFRAD and ISIS networks. This highlighted some shortcomings with the RAP and HRRR forecasts of incoming shortwave radiation. Most of our effort during Phase 1 of SFIP was focused on addressing these problems with a variety of model system improvements.

The RAP and HRRR models during the warm season of 2014 had a noticeable warm and dry bias in near-surface conditions over most of the central and eastern United States, and our new SURFRAD/ISIS verification revealed that there was also a large excess of incoming global horizontal irradiance in the models. We hypothesized that a lack of cloud cover (particularly low-level cloud cover) in the models was resulting in too much heating of the land surface. This, in turn, caused unrealistically strong surface heat fluxes and turbulent mixing in the planetary boundary layer (PBL), which further reduced the already deficient cloud cover.

We addressed these issues with a combination of data assimilation system modifications and model physics improvements. Many of our data assimilation changes were made with a view towards improving the near-term representation of clouds and precipitation. One of these changes involved better accounting for regions of weak reflectivity in the RAP cloud / hydrometeor assimilation system, in order to improve the representation of light precipitation in the RAP initial conditions and provide more realistic initial cloud cover. Additional modifications more accurately accounted for radar beam blockage and data gaps (particularly in the western United States), which improves shorter lead times forecasts of clouds and precipitation. We have also tested the assimilation of new data sources within the RAP and the HRRR, including radar radial velocity data and surface mesonet observations. Within the HRRR, we have tested the cycling of the 3-km land surface fields to allow a higher-resolution treatment of land surface processes.

In terms of model physics development for SFIP, we have implemented a shallow cumulus scheme within the RAP, and have made numerous improvements to the Mellor-Yamada-Nakanishi-Niino (MYNN) PBL scheme to address insufficient low-level cloud cover in the models. We have conducted tests incorporating the radiation effects of (parameterized) boundary-layer clouds within the modified MYNN PBL scheme (independent of the convective schemes). The Grell-Freitas-Olson shallow cumulus scheme has also been tested within the 3-km HRRR. Finally, we have also modified the RUC land surface model (LSM) treatment of the vegetation wilting point, reducing it to increase evapotranspiration and increase cloud cover in the boundary layer. All of these changes work in tandem to significantly improve the model forecasts of cloud cover, incoming shortwave radiation, and near-surface temperature and moisture.

Satellite

The role of NOAA/NESDIS in the Solar Forecasting Improvement Project is to provide Advanced Satellite Products (ASPs) for the two forecasting teams at NCAR and IBM. The ASPs are cloud, surface, and atmosphere products derived from geostationary satellite imagery at the highest possible spatial and temporal resolution – such quantities as cloud mask, cloud probability, cloud transmission, cloud top height, cloud top temperature, cloud effective particle size, etc. Ancillary data, such as elevation and numerical weather prediction fields are provided in the files at the same resolution as well. There are at this time 147 different variables in the ASP output, including quality flags and processing information.

The main goals for Year 1 of the project were to implement an Advanced Satellite Products system for the use of the IBM and NCAR teams, begin validation, and make any needed changes based on feedback from the teams.

ASP files are being produced every GOES Imager acquisition, which occur on a 15-30 minute schedule. Processing is done on a dedicated computer, with a turn-around time of 8-21 minutes from image acquisition to results available on ftp. Several helpful visualizations of the data are also created for users on web pages.

Users have been provided with a document titled "User's Guide for 1km Cloud Products Derived from GOES Imager Data using CLAVR-x", which discusses the basics of the source imagery, the process by which it is turned into Advanced Satellite Products, and considerations users should make when using the data. Validation of selected variables from the older 4km version of the products was also included.

Future work will concentrate on validation of the 1km products and improving the turn-around time, product variety, and product quality as needed.

Ground Observations

In the ground-based measurement effort, NOAA's main objectives are to provide high quality radiation products for validation and verification of short-term to day-ahead solar forecasts. More specifically for the three year project, our goals include (1) Maintaining and providing data from our 7 SURFRAD and 7 ISIS; (2) Update ISIS radiation measurements from 3 min to 1 min data: (3) Purchase and install new pyrheliometers for direct solar irradiance measurements at the 7 SURFRAD sites; (4) Building, testing, and deploying two mobile SURFRAD stations at two utility plants in collaboration with DOE sponsored partners, and includes ongoing maintenance and processing of the data at the mobile sites; (5) Upgrading the data acquisition and communications at 7 SURFRAD sites and 7 ISIS sites; (6) Providing radiation data at the 7 SURFRAD sites in near real-time; (7) Develop and provide aerosol optical depth and cloud images and cloud fraction at our two mobile sites; (8) Provide data recovery rates each year; (9) Provide temporally and spatially averaged radiation products for comparison to HRRR and RAP solar forecasts and advanced satellite products; (10) Provide a data-set for analysis of conversion of direct and diffuse to sloped surfaces; (11) and as time permits develop and provide spectral solar irradiance, cloud optical depth and spectral albedo from the mobile sites.

Milestones this year include working with the DOE sponsored teams to find locations to deploy two mobile SURFRAD stations. One existing unit was deployed at a 30MW PV facility in the San Luis Valley in collaboration with Xcel and the NCAR team in August, 2014. The second unit was built and tested at our facilities in Boulder, CO and deployed near Green Mountain Power's Education Center in Rutland, VT in collaboration with Green Mountain Power and the IBM Team in October, 2014. Data processing was implemented and the radiation data from these two mobile sites have been made available on our ftp server in near real-time. We also are providing images and cloud fraction from the TSI cameras for these two mobile sites on our ftp site. Another milestone was upgrading our data acquisition and communication systems at 7 SURFRAD and 7 ISIS sites. We accelerated our schedule for these upgrades to provide timely radiation products. These upgrades allow more reliable and near-real time radiation data delivery to the DOE sponsored teams to meet their goals. Lastly, we changed the data rate at the ISIS sites from 3 min to 1 min.

Background

Modeling

NOAA's modeling effort is focused around research and development within the Global Systems Division (GSD) of the Earth System Research Lab (ESRL) in Boulder, Colorado. Model changes are aimed at improving the representation of a variety of meteorological phenomena, for a diverse set of applications. Improvements within the system are extensively tested and verified, both in real-time parallel versions of the modeling system, and within controlled retrospective experiments. Positive improvements, in terms of a variety of variables, are quantified using a verification system incorporating a number of observational data types, including radiosondes, surface weather observations, radar reflectivity observations, and quantitative precipitation estimates. ESRL modeling system versions showing demonstrated improvements for all variables are then transitioned into the operational modeling suite at the National Centers for Environmental Prediction (NCEP), where they provide reliable real-time guidance for the National Weather Service and many other users.

Prior to the beginning of the SFIP, ESRL's experimental models were not systematically evaluated in terms of their forecasts of surface solar radiation variables. However, since solar radiation is so closely tied to many other meteorological phenomena, model shortcomings related to other variables also strongly affected the model radiation forecasts. Thus many of our ongoing modeling improvement efforts remained highly relevant for the SFIP. The forecast improvements achieved through SFIP also tangentially affect model performance in other areas. And since ESRL's experimental modeling effort is so closely tied to the operational modeling of NCEP, SFIP's achievements will ultimately lead to improved operational models.

Satellite

The Cooperative Institute for Meteorological Satellite Studies (CIMSS), located at the University of Wisconsin – Madison's Space Science and Engineering Center is a partnership between UW and the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS). At CIMSS, state and federal researchers are housed in the same building, working together to create new and impactful algorithms, methods, and data products for use at NOAA's National Weather Service, among other public and private agencies. CIMSS has a long history in creating information products from satellite instruments – information about how the atmosphere has behaved over decades of time in the past, information about how the atmosphere is behaving now, and information to help predict how the atmosphere will behave in the short and long term future. Our premier remote sensing data processing software used to derive information about cloud is called CLAVR-x/PATMOS-x (Foster and Heidinger, 2013; Heidinger et al., 2012; Walther and Heidinger, 2012). When used for processing in real-time is it called CLAVR-x and when used for processing retrospectively, it is called PATMOS-x. To date the PATMOS-x record has achieved consistency through vigorous inter-satellite calibration and participation in inter-comparison and inter-calibration initiatives such as the following:

- The Global Energy Water Cycle Experiment (GEWEX) Cloud Climatology Assessment
- The ESA Cloud Climate Initiative (CCI)
- The EUMETSAT Cloud Retrieval Evaluation Workshops (CREW)
- The World Meteorological Organization Sustained, Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) Pilot Project
- The Global Space-Based Inter-Calibration System (GSICS) program

The PATMOS-x cloud mask compares favorably against other well known global cloud products such as ISCCP and CLARA-A1 (Sun et al., 2015).

The role of NOAA/NESDIS/CIMSS in the Solar Forecasting Improvement Project is to provide Advanced Satellite Products (ASPs) for the two forecasting teams at NCAR and IBM. For the past several years, NOAA's operational products from geostationary satellites, known as GOES Surface and Insolation Products (GSIP), have been available at a 1/8 degree (about 13 km) resolution on an hourly basis (http://www.ospo.noaa.gov/Products/land/gsip/index.html). More recently, CIMMS has been using research algorithms to produce a similar suite of cloud and surface products from GOES at the thermal band resolution (nominally 4 km x 4 km at nadir) every 15 minutes (http://cimss.ssec.wisc.edu/clavrx/google_earth_main.html). Neither of these products take advantage of the full resolution of the data from the GOES Imager, whose visible band channel has a resolution of 1 km x 1km at nadir. In order to provide useful forecasts of clouds for the solar power industry, high resolution models are needed. These in turn require high resolution data to assimilate in order to have accurate initial conditions.

At CIMSS, therefore, our contribution is the Advanced Satellite Products: cloud, atmosphere, and surface products derived from GOES imagery at the highest possible resolution spatially and temporally. ASPs provide a 16-times finer resolution than the highest resolution products previously available. ASPs are provided to the two SFIP teams for their use in assimilating, diagnosing, and validating their solar power forecast models.

Ground Observations

NOAA's measurement effort is focused around research and development within the Global Monitoring Division (GMD) of the Earth System Research Lab (ESRL) in Boulder, Colorado. Our high quality observation sites will provide a suite of radiation products including global horizontal irradiance (GHI) and direct normal irradiance (DNI) and critical ancillary information for validation and verification of improvements in NOAA's HRRR Solar forecasts, NOAA CIMSS satellite products, and short to long-term solar forecasts developed by the NCAR and IBM teams sponsored by DOE's SunShot Initiative. NOAA's observational network includes 7 SURFRAD sites and 7 ISIS (Integrated Solar Irradiance Network) sites located across the continental United States (Figure 1), and two mobile platforms for short-term regional studies. We continue to work with colleagues at NREL, WMO (World Meteorological Organization), PMOD, BSRN (Baseline Surface Radiation Network), and DOE ARM/ASR (Atmospheric Radiation Program and Atmospheric System Research) to stay informed on best practices for solar radiation measurements and calibration.

The SURFRAD network measures the surface radiation budget across different climatic regions. The measurements include downwelling shortwave and long-wave irradiance, upwelling shortwave and longwave solar irradiance, diffuse and direct shortwave irradiance, total, direct, and diffuse spectral solar irradiance at seven wavelengths, photo-synthetically active solar radiation (PAR), ultraviolet radiation, aerosol optical depth, cloud images, and meteorological parameters including temperature, pressure, wind speed and direction, and relative humidity. The seven ISIS sites measure downwelling and upwelling shortwave and longwave solar irradiance, direct and diffuse solar irradiance, ultraviolet radiation, and meteorological parameters.

This comprehensive data-set will provide valuable information for addressing uncertainties in the solar resource used by utility plants. In addition to GHI the mobile SURFRAD unit will provide high quality diffuse (DHI) and direct solar irradiance (DNI) from a well-maintained site, as well as plane-of-array solar irradiance. The quantity of interest for utility operators is the plane–of-array solar irradiance (POA) that is often modeled using decomposition and transposition models. The solar irradiance measurements with ancillary information about the sky and atmospheric conditions including aerosol optical depth, surface albedo, and cloud fraction will provide a unique data-set for evaluating the performance and uncertainties in these calculations.

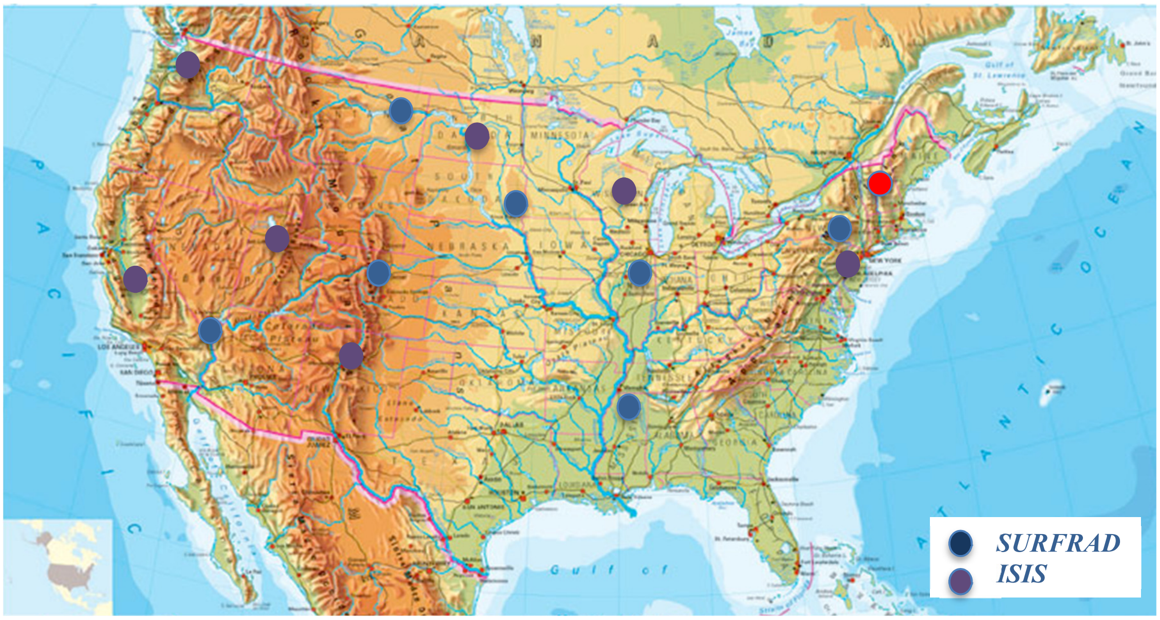

Figure 1: SURFRAD and ISIS site locations.

Introduction

Modeling

Most of NOAA's modeling effort associated with the SFIP has been focused on improvements to the data assimilation and modeling within the WRF-based 13-km Rapid Refresh model and the 3-km High-Resolution Rapid Refresh model. Data assimilation and model development is steered and evaluated through the use of an in-house verification system that verifies forecasts based on observations from a variety of instruments. Verification of temperature, relative humidity, and wind forecasts, both at the surface and aloft, based on radiosondes and surface METAR observations, are among the most important verification types, but through the SFIP we also developed the capability to verify our models against the high-quality observations from the SURFRAD/ISIS networks. All of our SFIP-related development described in this report was evaluated based on this verification system.

Development within GSD falls into an annual schedule necessitated by our close ties to the National Centers for Environmental Prediction (NCEP). During the summer and fall, development progresses with the goal of preparing a version of the models to be implemented at NCEP during the following spring or summer. This version is first implemented at GSD in the fall or early winter so that its performance can be evaluated in realtime runs as well as for retrospective spring and summer periods. During this first phase of the SFIP, much of the SFIP-related development resulted in a version of RAP and HRRR that was implemented at GSD on 1 Jan 2015, and the same version (with some additional improvements resulting from extensive evaluation at GSD) is targeted for NCEP implementation in summer 2015, subject to successful reliability testing at NCEP and a 30-day field evaluation by National Weather Service forecasters, as well as the scheduling of other implementations.

Satellite

A large part of increasing accuracy of forecasting solar power resources is to improve the forecasting of clouds on the arrays. By increasing the
It is anticipated that the real-time cloud products will be used in the solar irradiance modeling and short term forecasting stages in several ways (NCAR SOPO Task B.1, B.2; IBM SOPO Task 2.1). The cloud type (which includes phase), optical thickness, particle size, and water path along with the geometry variables solar zenith angle and solar azimuth angle will be used in the radiative transfer models to calculate fluxes at the surface. Clouds indicated by the cloud type variable will be advected by forecast model winds at the cloud height. The forecasting of cloud growth or dissipation will also make use of cloud type, particle size, and water path. Cloud properties in sequential images can used to derive winds and development/dissipation trends, which can be assimilated into forecast models. ASP users will use the data for training and validation (NCAR SOPO B.3; IBM SOPO 2.2, 2.3), and during the operational phase (NCAR SOPO C, IBM SOPO 3).

ASP cloud products will be evaluated for accuracy and utility by the users by comparing with ground-based sensors in the SURFRAD and ISIS networks and other instrumented locations (NCAR SOPO B.1.4.4; IBM SOPO 2.2.1, 2.3.1). The NOAA/NESDIS ASP providers will assist users in interpreting the quality of the cloud products by providing results from previous studies and conveying informed opinion regarding the strengths and limitations of each data product. Any cloud algorithm improvements developed during the course of the project will be implemented unless the users request a static version for the duration of the project.

Ground Observations

NOAA's measurement effort is primarily focused on providing high quality radiation observations and critical ancillary information for validation and verification of NOAA's HRRR solar forecasts, NOAA CIMSS satellite products, and short to long-term solar forecasts developed by the NCAR and IBM teams sponsored by DOE's Solar Forecasting Project within the SunShot Initiative.

The major goals for Phase I are (1) Maintaining and providing data from our 7 SURFRAD and 7 ISIS; (2) Updating the direct solar irradiance measurements at the 7 SURFRAD sites; (3) Building, testing, and deploying two mobile SURFRAD stations at two utility plants in collaboration with DOE sponsored partners, and includes ongoing maintenance and processing of the data at the mobile sites; (4) Upgrading the data acquisition and communications at 7 SURFRAD sites and 7 ISIS sites; (5) Providing radiation data at the 7 SURFRAD sites in near real-time; (6) Develop and provide aerosol optical depth and cloud images and cloud fraction at our two mobile sites.

We are on track or ahead for the majority of our planned tasks in Phase I. Milestones this Phase include providing timely radiation data from 7 SURFRAD sites and 7 ISIS (Integrated Solar Irradiance Network) sites. In addition to the 14 permanent sites, we worked with the DOE sponsored teams to find locations to deploy two mobile SURFRAD stations. Two mobile radiation platforms were developed, tested and deployed at two sites located at PV solar utility plants in collaboration with our utility partners (Xcel Energy and Green Mountain Power) at two distinct geographical locations. These two units were deployed in the San Luis Valley of Colorado in July, 2014 and the second unit in Rutland, VT starting in October 2015. Another milestone was upgrading our data acquisition and communication systems at 7 SURFRAD and 7 ISIS sites. We accelerated our schedule for these upgrades to include all the sites to provide timely radiation and cloud products. Our tasks only called for 7 sites upgraded in the first year but we moved forward on this task to address the needs of other team members.

New deployments always have unplanned challenges. We incorporated at the start of the mobile campaign visual daily plots and checks to discover issues as early as possible. These challenges were caught early and dealt with as rapidly as possible to reduce loss of data. Issues with instrumentation should be significantly reduced as the campaign proceeds. The section on "Project Results" describes more in detail these challenges and solutions.

Upcoming challenges for the fourth quarter include installation of the pyrheliometers at the SURFRAD sites. We have tasks to purchase and deploy new pyrheliometers for measuring direct normal irradiance at 3 SURFRAD sites during Q4 of Phase I. We have investigated available products and evaluated their specifications, and the instruments have been purchased and delivered. But deployment of the first three will likely be delayed into the next phase of the project (Phase II). This delay is discussed in the "Project Results" section.

Project Results and Discussion

This section is broken into two parts: 1.) Work Planned for Phase 1, and 2.) Narrative Results and Discussion – for each of the three main areas of contribution – modeling, satellite, and ground observations.

Modeling

Work Planned for Phase I (1 May 2014 – 30 Apr 2015)

A.1. Determine standardized metrics. In Phase I, NCAR and NOAA were to collaboratively identify standardized metrics for use in evaluating forecasts from the variety of statistical and physical models developed in association with the SFIP, including the coupled RAP/HRRR system. Determination was to be based upon input from utility managers, other projects members, and various stakeholders in the solar energy industry. These standardized metrics were to be incorporated into verification systems in order to evaluate the various models on a level footing. Among the models to be evaluated was NCAR's WRF-Solar.

A.2. Determine baseline values for metrics. During Phase I, NCAR and NOAA were to establish baseline values for the metrics determined in section A.1. These values were to be incorporated into the NOAA verification system for use in evaluating the RAP and HRRR models as well as WRF-Solar. NOAA verification was to be complemented by NCAR's MET system verification.

A.3. Determine target values for metrics. In Phase I, collaboration with NCAR and IBM was to aid in determining target values for the metrics determined in section A.1. We were to evaluate model performance of the RAP and HRRR based on comparing these target values with results from our recently-developed verification capability based on SURFRAD/ISIS observations.

B.1.1. Testing and improvement of HRRR system (including data assimilation and model components). In Phase I, our goal was to begin intensive testing and evaluation of promising modifications to the HRRR data assimilation and modeling system, aiming towards improving irradiance forecasts. Many of these changes were seeking to improve boundary-layer cloud coverage in the HRRR, since we discovered (through the SURFRAD/ISIS verification capability) a significant deficit in cloud coverage in the models. Additional changes were aimed at improving land surface conditions in the HRRR. A significant group of improvements were to be tested and evaluated as a group as a prospective next version of the HRRR system at NCEP, and an initial chunk of code was to be transitioned to NCEP for their preparations for the system upgrade in June of 2015.

B.1.2. Testing and improvement of RAP system (including data assimilation and model components). In Phase I we were to begin testing modifications to the RAP data assimilation and modeling system, with the goal of improving both the direct RAP forecasts of irradiance, and the initial and boundary conditions provided to the HRRR. Much of the work on the RAP system was to focus on the assimilation of new observation types, as well as the treatment of subgrid scale, parameterized clouds. A group of changes was to be evaluated for the version to be transitioned to NCEP for the operational upgrade in June of 2015.

B.1.3. Evaluation of real-time RAP-chem and HRRR-chem runs and assimilation cycles (to provide real-time aerosol forecasts to complement HRRR GHI/DHI/DNI forecasts). During Phase I, real-time forecast grids from the RAP-chem and HRRR-chem models were to be provided to NCAR for their evaluation and verification. The aerosol forecasts from the models were to be examined to determine their effects on radiation. NOAA was to work towards providing a time-varying aerosol optical depth field from the RAP-chem.

B.1.4. Provide gridded forecast datasets from GSD real-time experimental model systems (including GSD RAPv2 and HRRR) *and provide consultation on use of datasets.* During Phase I, model grids from the experimental ESRL RAP and HRRR were to be provided to SFIP team members, including NCAR and IBM. NOAA was to provide consultation and technical support on the use of the model fields to these other teams.

B.2.1. Internal GSD evaluation of solar irradiance guidance from RAP and HRRR. During Phase I, GSD was to develop a verification capability based on high-quality surface radiation measurements from the NOAA SURFRAD and ISIS networks for use in evaluating model forecast performance for the RAP and the HRRR. Verification was to begin with the global horizontal irradiance, and then be extended to include the direct normal and diffuse horizontal irradiance components. The metrics determined by the NCAR and NOAA teams were to be incorporated into the verification system to aid in evaluating changes to the data assimilation and modeling systems.

B.2.2. Collaborative comparison and evaluation of solar irradiance guidance from RAP and HRRR. In Phase I, GSD was to collaborate with the NCAR and IBM teams to compare and evaluate solar irradiance guidance from the models, using both the in-house GSD verification system and external verification projects.

B.2.3. Work with WRF developers. In Phase I, GSD planned to work closely with WRF developers at NCAR to evaluate and test the latest version of the community-supported WRF code, including several physics packages with significant changes since the previous version. Physics packages examined include the RRTMG shortwave/longwave radiation scheme, the MYNN PBL scheme, the Grell-Freitas-Olson cumulus and shallow cumulus schemes, and especially the new aerosol-aware Thompson microphysics scheme.

B.3. Milestones. During Phase I, the ESRL experimental versions of the RAP and HRRR were to be updated in the autumn of 2014 with the latest data assimilation and model improvements coming out of the SFIP. In addition, this set of code changes, plus some additional ones tested in early 2015, are to be transitioned to operations at NCEP in the spring of 2015. This set of code will constitute the next operational versions of the RAP and HRRR.

Satellite

Work Planned for Phase I (1 May 2014 – 30 Apr 2015)

B.4. Provision of advanced satellite products. During Phase I, CIMSS was to provide a stream of real-time products over the contiguous USA from the NOAA GOES Imagers at the full temporal and spatial resolution of the sensors. Accuracy of the previously existing 4km product was planned, as was the start of validation of the 1km version.

Ground Observations

Work Planned for Phase I (1 May 2014 – 30 Apr 2015)

B.5.1 High-quality observations sites (SURFRAD and ISIS sites)

Data acquisition, processing, editing, and QA/QC analysis of one year's worth of surface irradiance data from our 14-site network were planned. This network (7 SURFRAD + 7 ISIS) collects continuous high-time resolution high-quality solar and infrared downwelling and upwelling irradiances to be used for ongoing verification and validation of short-term and day-ahead solar forecasts from NOAA's HRRR and RAP solar forecasts, CIMSS advanced satellite products, and the DOE sponsored teams. At the end of Phase 1, we were to report on the data retrieval rate at the 7 ISIS sites, 7 SURFRAD sites, and 2 mobile sites.

B.6.1 Movable SURFRAD Units

The primary task for the first year was to work with our utility partners to find suitable locations at a PV or CSP utility plant to deploy our two mobile platforms one for each DOE sponsored team (IBM team and NCAR team). The planned tasks included building, and testing of a second mobile SURFRAD platform similar to our existing mobile SURFRAD platform. The other planned task was to deploy two mobile platforms as chosen by our two partners each for one year. After deployment, the tasks were to maintain these new sites and provide radiation and cloud fraction data in near real-time.

B.7. Real-Time SURFRAD Measurements

A major task of Phase I was to improve the data acquisition and communications hardware at half of the SURFRAD sites. This task will assist our partners to achieve their goals for validation of their model forecasting components that provide short to day-ahead solar forecasts. This was a considerable effort to visit 7 sites across the year and upgrade the infrastructure. Travel costs were leveraged using NOAA base funds by combining the upgrades with scheduled annual visits.

B.7.1 SURFRAD and ISIS data products

During phase I, we were tasked with updating the ISIS network from 3 min to 1 min average for better comparisons with model and satellite data products. We were tasks also with providing data recovery rates for each of the sites for each year.

In addition, we were tasked with providing cloud images, cloud fraction and aerosol optical depth at our mobile sites. We are also tasks with providing temporally and spatially averaged radiation products for comparison to HRRR and RAP solar forecasts and advanced satellite products.

Modeling

Narrative Report and Update

A.1. Determine standardized metrics. During Phase I, IBM, NCAR and NOAA collaboratively identified several model-to-model comparison metrics, in addition to several metrics associated with the quantification of economic value. These metrics are broken up into base metrics and enhanced metrics (Table 1).

	Model-to-Model Comparison	**Economic Value**
Base Metrics	Mean absolute error Root mean square error Distribution (including statistical moments and quantiles) Categorical statistics for events	Operating reserves analysis Production cost modeling
Enhanced Metrics	Maximum absolute error Pearson's correlation coefficient Kolmogorov-Smirnov integral Statistical tests for means and variance Renyi entropy OVER metric Brier score Receiver operating characteristic (ROC) curve Calibration diagram Probability interval evaluation Frequency of superior performance Performance diagram for events Taylor diagram for errors	Cost of ramp forecasting

Table 1: Metrics for solar power forecasting

During Phase I, most of the base metrics were incorporated into the GSD internal verification system for the RAP and the HRRR, including mean absolute error, root mean square error, and bias. Evaluating the RAP and HRRR models based on these statistics is helping to identify further model developments to be undertaken in future phases. Figure 2A shows the average diurnal cycle of mean absolute error for the RAP and the HRRR during the winter of 2014-15 (Dec-Feb).

This verification system is also being applied to NCAR's WRF-Solar forecast grids, to allow a direct comparison with the GSD RAP and HRRR. These comparisons will help guide development in the future, both within the NOAA team and for the NCAR team.

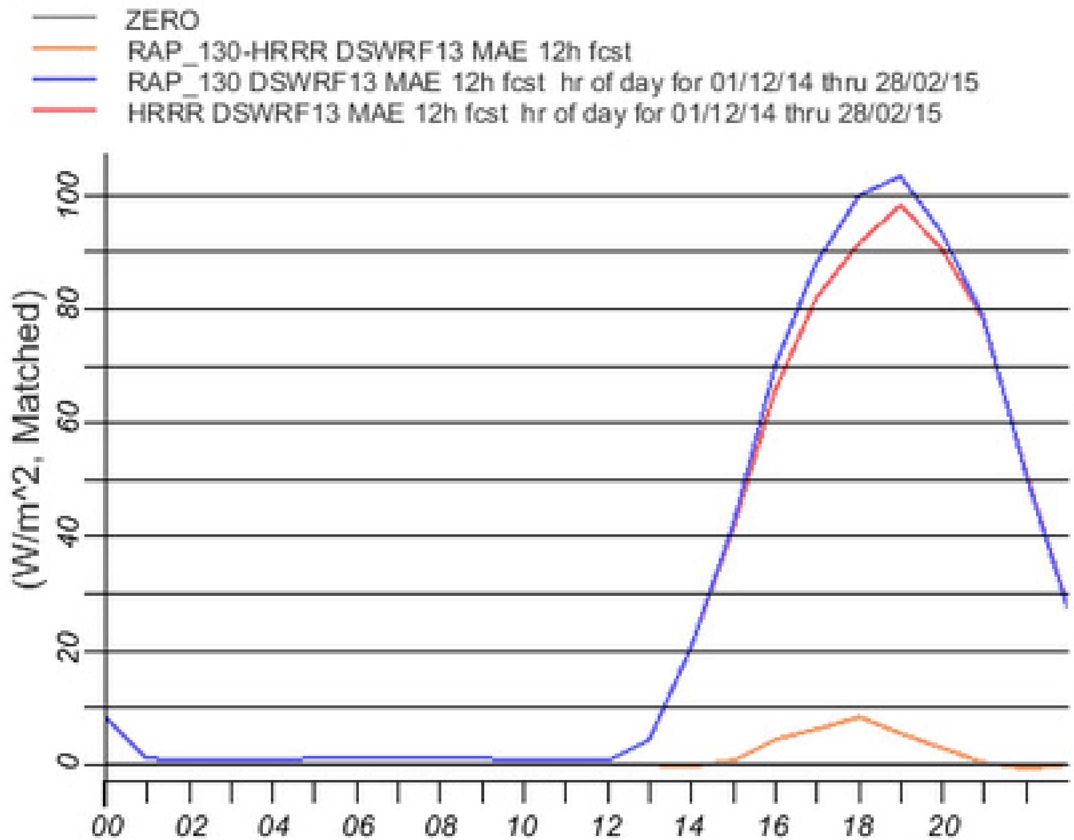

Figure 2A: Mean absolute error of 12-h forecasts of global horizontal irradiance GHI; W/m²) from the RAP (blue curve) and HRRR (red curve), verified against measurements from 14 SURFRAD/ISIS sites, and averaged over the winter of 2014-15 (1 Dec 2014 – 28 Feb 2015).

A.2. Determine baseline metrics. In Phase I, NOAA began to analyze realtime verification of the RAP and HRRR forecasts of global horizontal irradiance (GHI) against the SURFRAD/ISIS measurements. While this network consists of only 14 stations, the observations are considered very high quality, and they sample a large range of climate variability over the continental United States. NOAA is also carrying out verification based on a large number of other observation types, including radiosondes, surface METAR observations, composite radar reflectivity data, and quantitative precipitation analyses. Figure 2B is an example of the point verification that we can carry out for the RAP and the HRRR based on the SURFRAD/ISIS network.

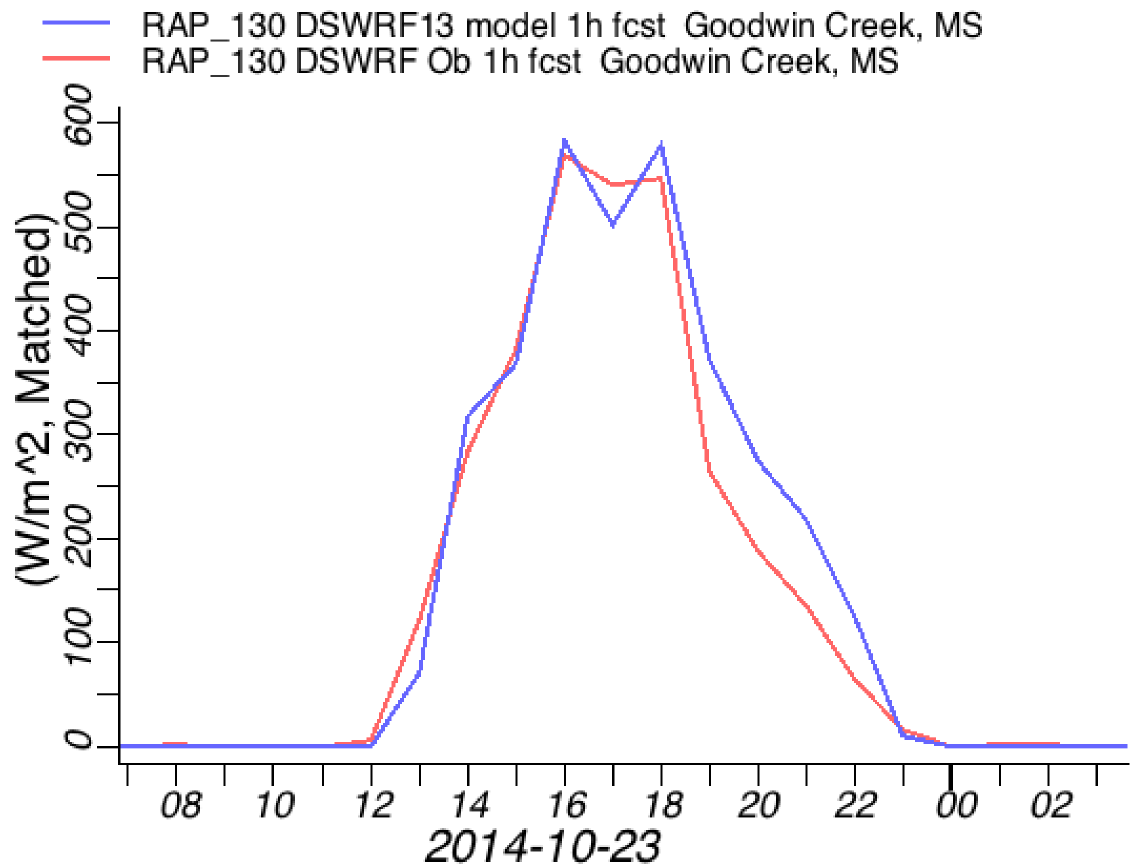

Figure 2B: Comparison between RAP 1-h forecasts (red) and SURFRAD observations (blue) of global horizontal irradiance (GHI; W/m²) at Goodwin Creek, Mississippi, from 07 UTC 23 Oct through 03 UTC 24 Oct 2014.

A.3. Determine target metrics. NCAR and IBM have determined target values for the performance of their models in terms of certain power-generation metrics. They have also established the following hour-ahead base metric values for irradiance forecasts (global horizontal irradiance): mean absolute error of 12 W/m^2, root mean square error of 12.5 W/m^2, MBE of 4.5 W/m^2, standard deviation of 49 W/m^2, variance of 2401 W/m^2, and interquartile ratio of 0.5 W/m^2. These are 24-h averages, not values just during the daylight hours.

B.1.1. Testing and improvement of the HRRR system. An improved version of the HRRR model was implemented at GSD in April of 2014. Figure 3 shows the model configuration at GSD during the summer of 2014. As discussed in our statement of work, we have an annual upgrade schedule, outlined in Figure 4. On 30 September 2014, the HRRR was operationally implemented at NCEP. This was an earlier version of the model, but later in 2014 and early 2015 work continued to upgrade the ESRL experimental version of the HRRR. The upgrades in the GSD experimental version in April 2014 included some bug fixes to the hydrometeor analysis, an enhancement to the assimilation of surface dewpoint observations by accounting for the difference in height between the observation and the height of the lowest model level, and a reduction of the latent heating applied to the HRRR (based on radar reflectivity observations) during a one-hour pre-forecast period. We expect these changes to improve the representation of the convective environment, and thus the representation of convective clouds, and the resulting radiation interactions.

More recently, we introduced and extensively tested the new Grell-Freitas-Olson shallow cumulus scheme. This scheme is "scale aware", meaning it can be applied at a variety of scales, and it is linked to the RRTMG shortwave radiation scheme. This results in improved shallow convective cloud cover, and less global horizontal irradiance (GHI) reaching the surface (see Figure 5).

We tested for the first time the hourly cycling of land surface fields within the 3-km HRRR, allowing a higher-resolution treatment of land surface processes; these more realistic surface fields will have an impact on the model's low-level cloud fields. We have tested the assimilation of radar radial velocity data, as well as surface mesonet data, within the RAP and the HRRR. We also worked towards upgrading to the latest version of the Gridpoint Statistical Interpolation 3DVAR data assimilation system. We have also tested accounting for the attenuation of incoming solar radiation by (parameterized) boundary-layer clouds within the MYNN PBL scheme. After extensive realtime testing we reduced the wilting point of vegetation in certain soil types in order to increase evapotranspiration, which increases low-level cloud cover and improves solar irradiance verification.

ESRL RAPv3 and HRRR 2014

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.5.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTMG/ RRTMG	Thompson v3.5.1	GF	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.5.1+	GSI 3D-VAR/ Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson v3.5.1	None	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	5 min	MODIS Fractional	0.07 K/s	20 s

Figure 3: ESRL experimental RAP and HRRR configurations during 2014.

HRRR/RAP annual upgrade schedule

	Spring-Summer	Fall-Winter
RAP/HRRR model/ assimilation upgrade at ESRL **(Step 3)**	**(Feb-Mar)** • Major change package each year for model and assimilation – upgrades to ESRL HRRR-primary and RAP-primary versions after substantial ESRL testing	**(Oct-Nov)** Smaller change package with known improvements tested and ready for implementation - optional
RAP/HRRR model/ assimilation upgrade at NCEP **(Step 5)**	**(April-June)** Target for Implementation	**(Nov-Feb)** • Transfer of code to NCEP starts in this period • Same change package as finalized at ESRL • Not implemented until additional extensive testing is completed at both EMC and NCO. • Final implementation will not occur until following spring-summer season. • NCEP readiness dates for EMC testing or NCO implementation may change from year to year
WRF/ assimilation code from NCAR to ESRL **(Step 2)**	**(May-Sept)** • Spring WRF major version release • WRF-solar-specific upgrades (esp. after SunShot Phase A) • Assimilation modifications possibly useful for HRRR/RAP	**(Nov)** • WRF sub-version release • Other SunShot changes as available • optional

Figure 4: ESRL model upgrade schedule. Steps in left column refer to the ESRL-NCEP development process discussed in the NOAA statement of work for SFIP.

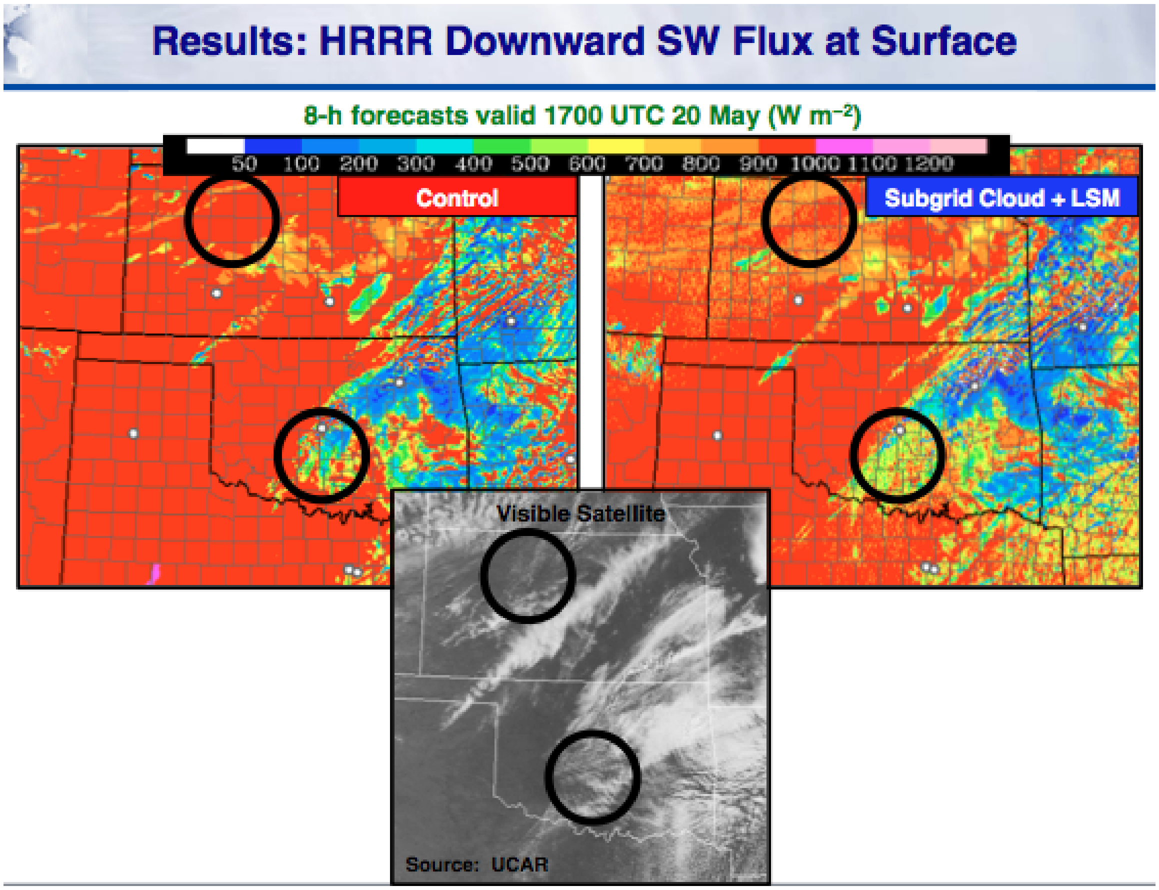

Figure 5: 6-h HRRR forecasts of global horizontal irradiance (GHI; W/m²) valid at 1700 UTC 20 May 2013 compared with visible satellite imagery; (left) summer 2014 version of the HRRR run in retrospective mode, and (right) version of the HRRR with MYNN subgrid cloud modifications and reduced wilting point within the land surface model. The black circles highlight areas of improved forecasts in the new version of the HRRR.

B.1.2. Testing and improvement of the RAP system. The experimental version of the RAP run at GSD, like the HRRR, has also experienced extensive modification since April 2014 as a result of careful detection and diagnosis of systematic forecast errors. The RAP contains many of the same data assimilation and model changes as the HRRR (described in section B.1.1). In the RAP, we have adopted most aspects of the WRFv3.6.1 code released by NCAR in August 2014, and introduced RAP enhancements not yet in the NCAR WRF repository.

In October 2014 we updated to the latest version of the Gridpoint Statistical Interpolation data assimilation code. We have also been actively improving aspects of the data assimilation that are unique to the RAP and HRRR. We continue to explore ways of improving our hydrometeor assimilation in regions of weak reflectivity to improve our representation of lightly-precipitating clouds. In addition, we have corrected some problems with our radar data assimilation associated with beam blockage in complex terrain, which results in more realistic cloud and precipitation structures in these areas. One major development in the RAP not contained in the HRRR is the introduction of a cycled satellite radiance bias correction within the data assimilation. Several additional satellite sensors have also been added to the list of assimilated instruments. Most recently, we have corrected a problem in the data assimilation wherein many extreme cold observations in Alaska and the western United States were being rejected because of a quality flag problem; this fix helps us represent near-surface temperatures better during extreme cold and stable situations, and will also help with the forecasting of fog in these regimes. Finally, we have begun interaction with scientists at NCAR and elsewhere to lay the groundwork toward developing an Ensemble Kalman Filter (EnKF)-based or hybrid variational / EnKF based assimilation of hydrometeors for use in RAP and HRRR.

We have also made extensive changes to the parameterization of physical processes in the RAP since April 2014. The Grell-Freitas deep convective parameterization has been improved within the RAP. Due to the Global Forecast System (GFS) upgrade at NCEP in early 2015, all versions of the RAP now contain improved and higher-resolution lateral boundary conditions, as well as higher-resolution ensemble data for the hybrid data assimilation. The WRFv3.6.1 code release contains a bug fix to the “swint” option that allows interpolation (based on astronomy only) of GHI between calls to the radiation modules. The radiation scheme has also been upgraded to RRTMG, which incorporates climatological aerosol information (see Fig. 6). Testing continues on the new aerosol-aware microphysics scheme (the Thompson-Eidehammer scheme developed at NCAR) compatible with the latest WRF; see Fig. 7). We have also tested the latest version of the Grell-Freitas-Olson shallow convection scheme; it appears to result in more realistic cloud cover, similarly to the HRRR (see Fig. 8). Improvements have also occurred within the MYNN PBL scheme, including now allowing the mixing of cloud water and cloud ice (see Fig. 9).

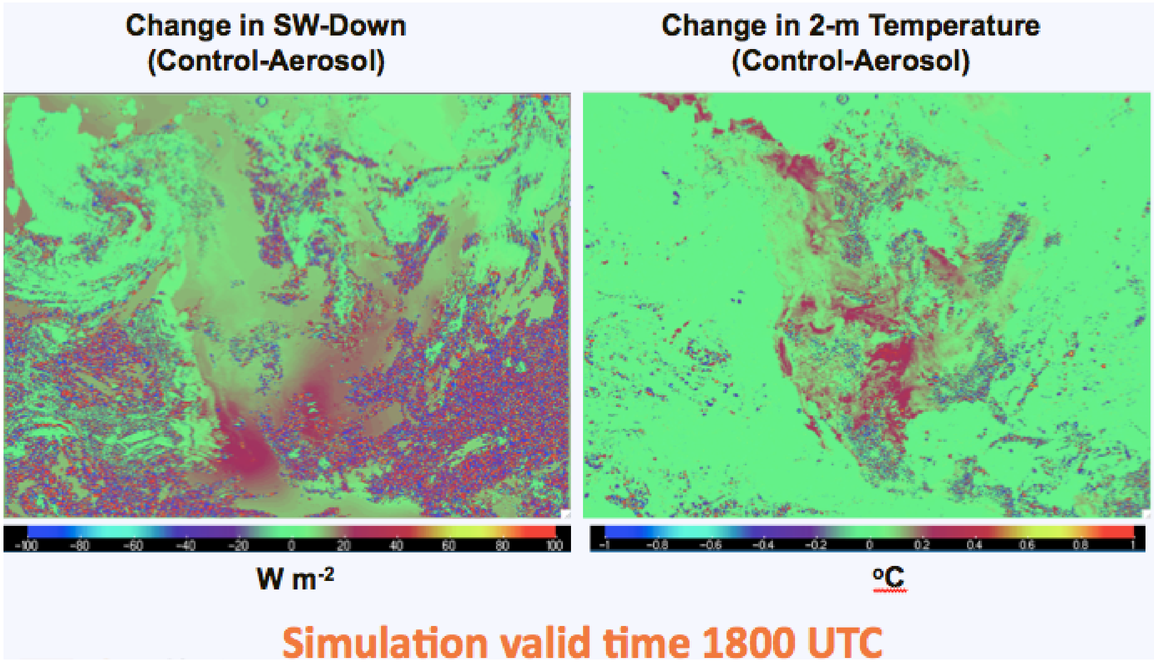

Figure 6: Effect on global horizontal irradiance (left; W/m²) and 2-m temperature (right; °C) of not using climatological aerosol information versus using the climatological aerosol information within the RRTMG shortwave radiation scheme.

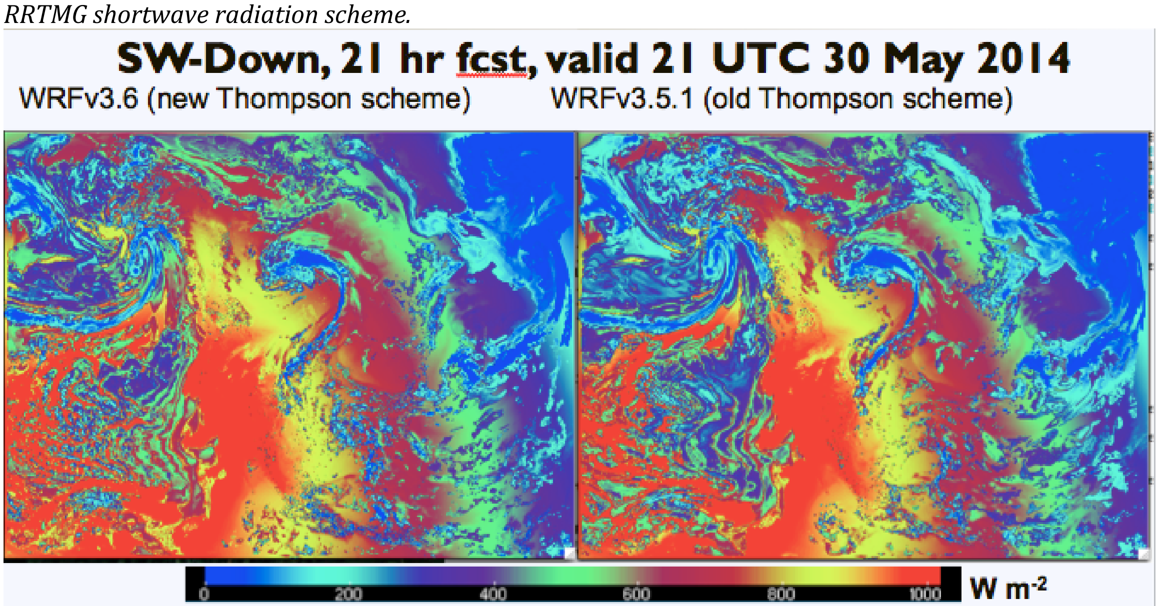

Figure 7: 21-h forecasts of global horizontal irradiance (GHI; W/m²) valid at 21 UTC 30 May 2014 from (left) WRFv3.6 with the aerosol-aware Thompson microphysics scheme and from (right) WRFv3.5.1 with the old no-aerosol Thompson microphysics scheme. The map area covers North America. The new Thompson scheme increases GHI over the eastern Pacific and decreases it over the eastern United States.

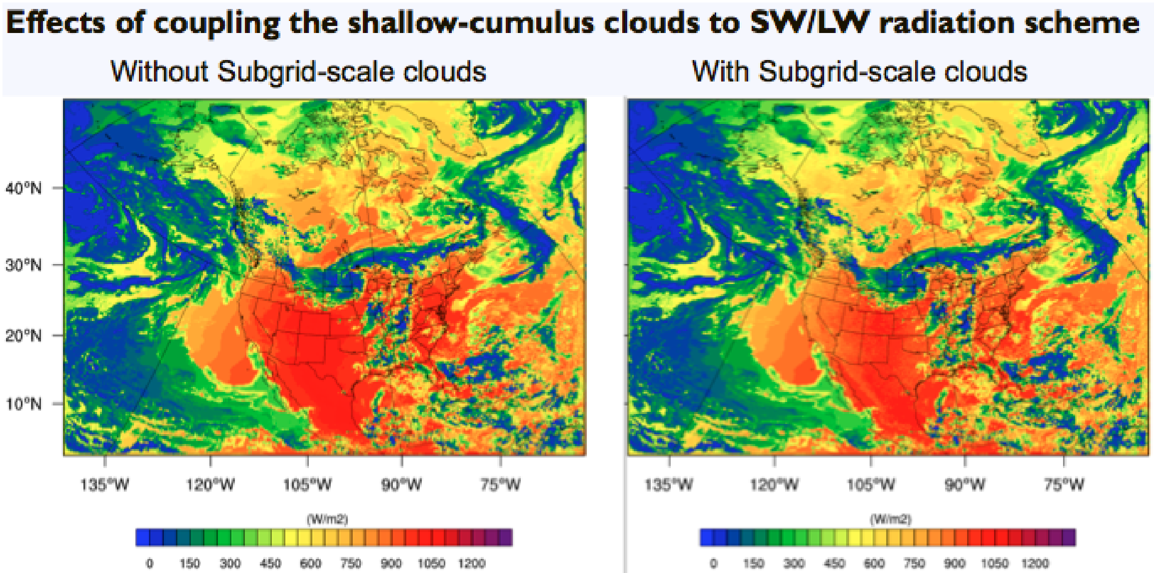

Figure 8: 6-h forecasts of global horizontal irradiance (GHI; W/m²) valid at 12 UTC 31 May 2013 from (left) a version of the RAP without subgrid-scale clouds coupled to the shortwave/longwave radiation scheme and from (right) a version of the RAP with coupling between the subgrid-scale clouds and the shortwave/longwave radiation scheme.

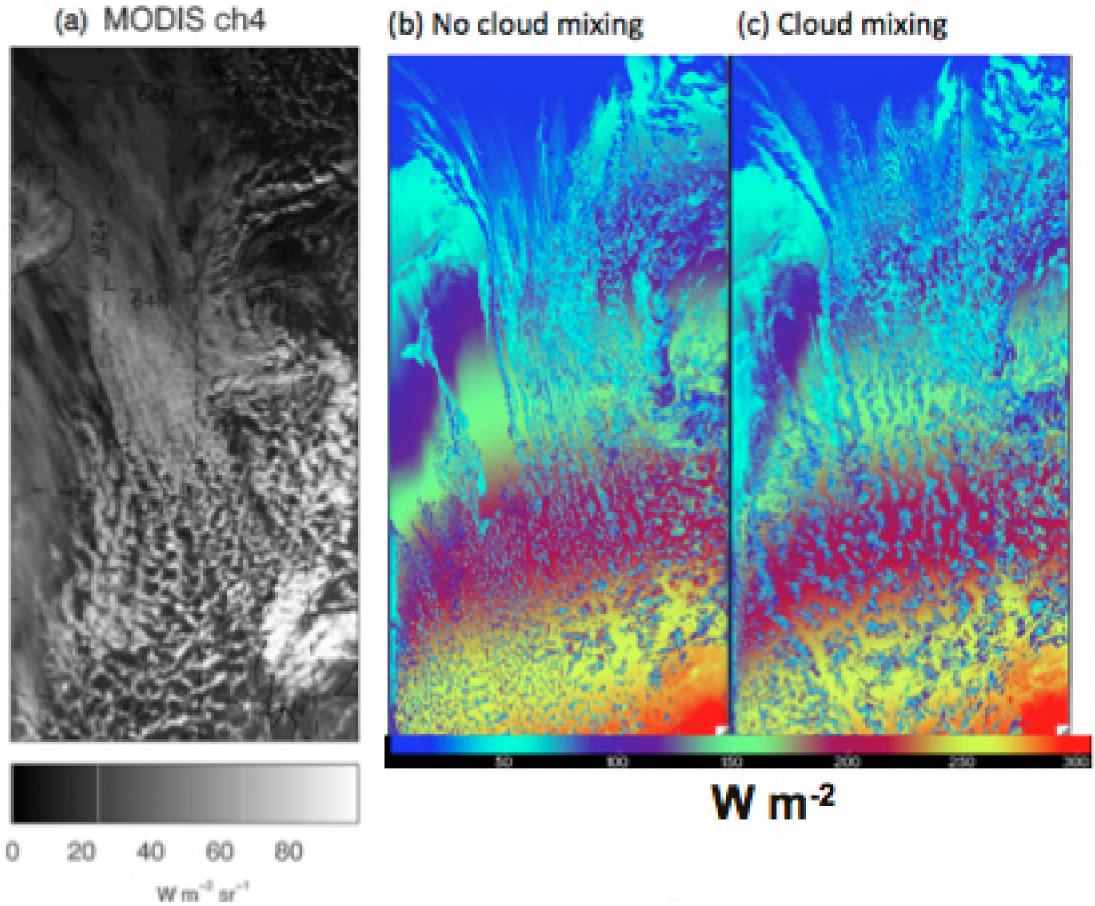

Figure 9: (left) MODIS visible satellite imagery and (right) forecasts of global horizontal irradiance (W/m^2) valid at 12 UTC 31 Jan 2010. The middle panel shows a WRF run with no cloud mixing within the MYNN PBL scheme, and the right panel shows a WRF run including this cloud mixing.

B.1.3. Evaluation of realtime RAP-chem and HRRR-chem runs and assimilation cycles. Sample RAP-chem and HRRR-chem forecast files have been transferred to NCAR for their evaluation. The presence of aerosol sources and sinks in the RAP-chem and HRRR-chem will help with solar irradiance forecasts.

B.1.4. Provide gridded forecast datasets from GSD realtime experimental model systems. We have been providing realtime access to our GSD experimental RAP and HRRR guidance (which are more advanced than the versions in place at NCEP) to a large number of private solar forecasting companies, as well as our partners at the NCAR and IBM SunShot teams. Since the winter of 2013-14, our team has been participating in weekly IBM and NCAR teleconferences, and providing answers to questions regarding model output fields and diagnostics.

B.2.1. Internal GSD evaluation of solar irradiance guidance from RAP and HRRR. The global horizontal irradiance (GHI) output from the RAP and HRRR is being verified against the high-quality point observations of the SURFRAD/ISIS network. The GHI is also broken down into its components of direct horizontal irradiance (which is direct normal irradiance (DNI) multiplied by the cosine of the solar zenith angle) and diffuse horizontal irradiance (DHI = GHI – cos(Θ)*DNI); these values are compared against SURFRAD/ISIS observations of the components. In addition, we continue to carry out point verification against surface METAR observations and upper-air radiosondes, and gridded verification of composite reflectivity and precipitation, to help us in error attribution and in quantifying the effects of possible model changes.

B.2.3. Collaborative comparison and evaluation of solar irradiance guidance from RAP and HRRR. Point verification from the SURFRAD/ISIS network has been very helpful for gauging the performance of the models, as well as the impact of candidate model changes that we test. Figure 10 shows an example plot of GHI from the RAP-primary cycle at ESRL, the HRRR, and our developmental RAP (dev2), compared against the SURFRAD observations. The RAP-dev2 includes some of the shallow cloud enhancements discussed above under B.1.2 and represents improved performance of RAP/HRRR with changes that may be implemented at NCEP as part of the RAPv3 and HRRRv2 in summer 2015. This plot shows the recent improvements achieved in the RAP-dev2.

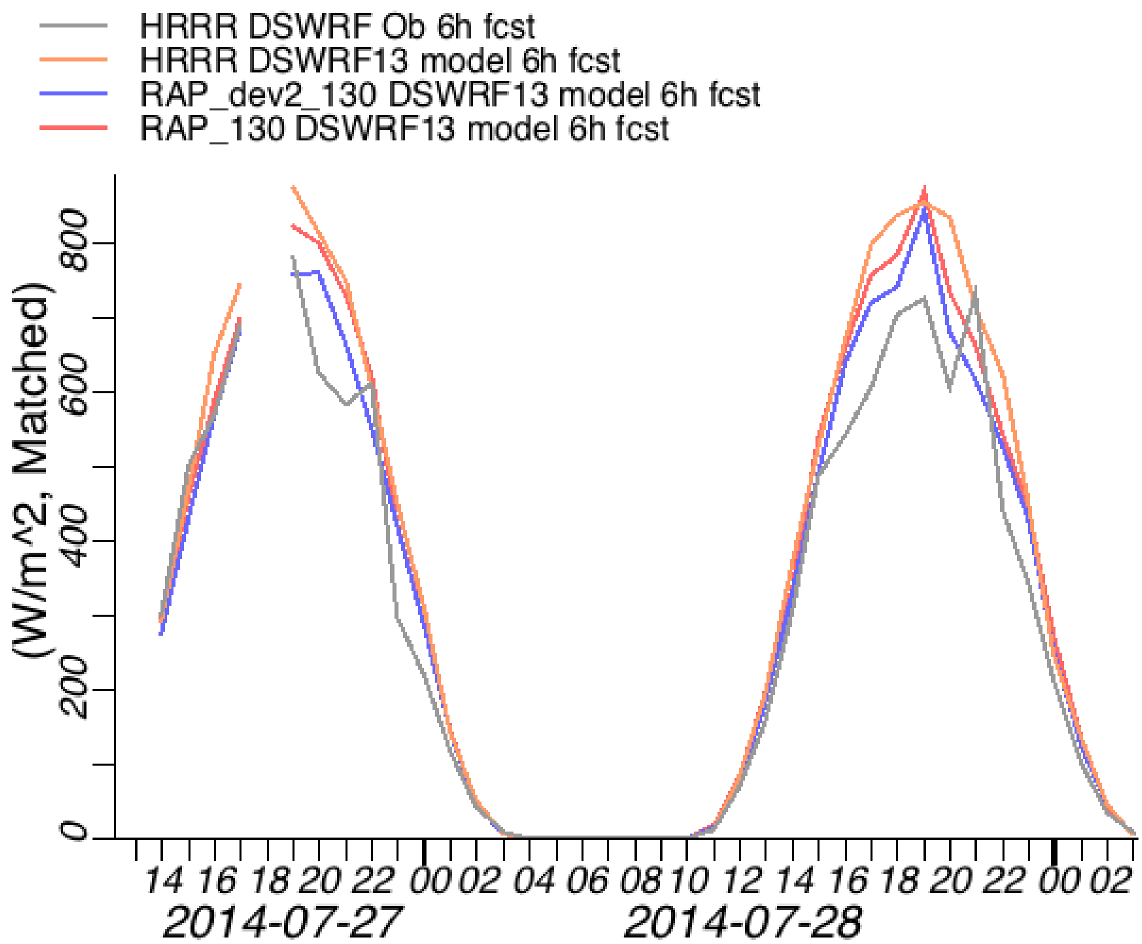

Figure 10: Comparison between HRRR 6-h forecasts (orange), RAP 6-h forecasts (red), RAP-dev2 6-h forecasts (blue), and SURFRAD/ISIS observations (grey) of global horizontal irradiance (GHI; W/m²) averaged over all SURFRAD stations, from 12 UTC 27 Jul through 03 UTC 29 Jul 2014.

B.2.3. Work with WRF developers. During our model testing and parameterization improvement process, we continuously collaborate with WRF developers at NCAR and elsewhere. Our use of a centralized code repository allows different developers on our team to check in and out versions of the code while maintaining a reliable record of changes made, including changes made and then retracted. Well-vetted changes to the code, particularly to the RUC land-surface model, the Grell convection and the Mellor-Yamada-Nakanishi-Niino boundary-layer code, are made available to the WRF developers at NCAR for possible inclusion in the NCAR WRF code repository at the discretion of the NCAR developers. For example, several such changes were included in the major WRFv3.6 code release made in April of 2014. In this way, our changes to WRF are made available to the larger WRF community.

B.3. Milestones. As planned, new and improved versions of the RAP and HRRR were implemented at GSD in April of 2014. The initial HRRR implementation at NCEP was made operational in September 2014. An additional upgrade to the GSD experimental versions of both the RAP and HRRR models occurred on 1 Jan 2015. These versions are very close to what is planned for NCEP implementation in summer 2015. Code for these versions is being made available to NCEP for pre-implementation testing in March 2015.

Satellite

Narrative Report and Update

B.4. Provision of advanced satellite products. The NESDIS role in the Solar Forecasting Improvement Project is to provide Advanced Satellite Products (ASPs) at CIMSS for the two forecasting teams at NCAR and IBM. To review, Advanced Satellite Products are cloud, atmosphere, and surface products derived from GOES imagery at the highest possible resolution. These are produced at the 1km visible pixel resolution, whereas previously, the highest resolution at which these same types of products had been available was at the 4km thermal pixel resolution. ASPs provide a 16-times finer resolution than the standard products.

Previous to the commencement of this project, we had been running a proof-of-concept version of the ASPs using GOES-East imagery. We modified this proof-of-concept version slightly and implemented it to run on a continuous basis. Processing for GOES-West was scripted, tested, and implemented. Figure 111 shows samples of cloud transmission from simultaneous GOES-West and GOES-East images. This work was presented to the solar community at large at the Sunshot Summit (Molling et al, 2014).

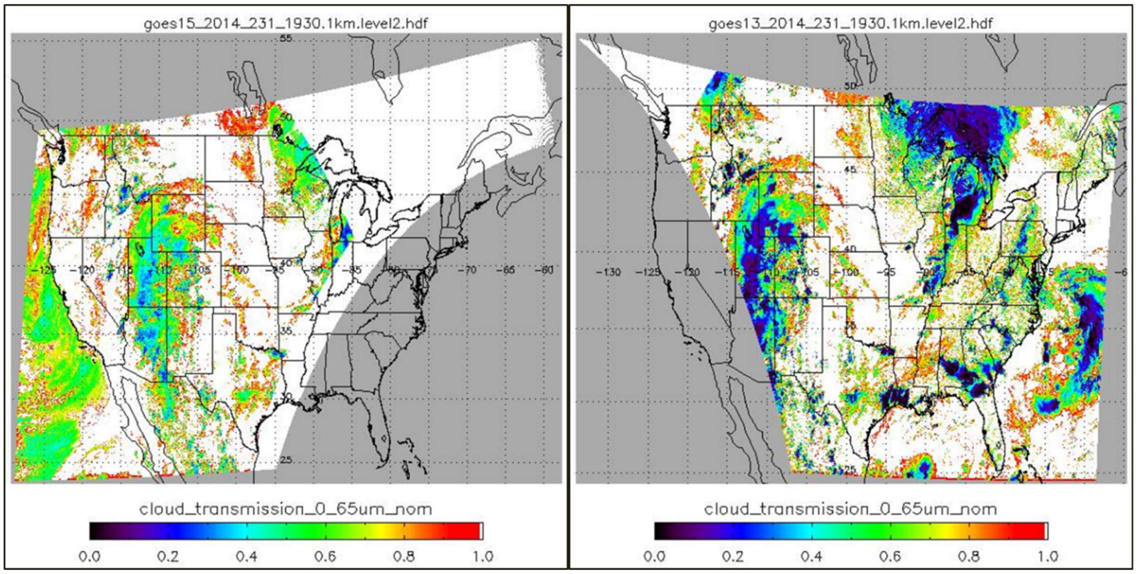

Figure 11: A sample Advanced Satellite Product: cloud transmission calculated from GOES-West and GOES-East Imager at the resolution of the visible band. Images were from Sep 28, 2014 at 1930 UTC.

An ASP file is made for each GOES every 15-30 minutes, according to the GOES Imager schedule. A computer for dedicated processing (had been running on shared resource) was purchased and the GOES-West and GOES-East processing was transferred to it. The ASPs include such quantities as cloud mask, cloud probability, cloud transmission, cloud top height, cloud top temperature, cloud effective particle size, etc. Ancillary data, such as elevation and numerical weather prediction fields are provided in the files at the same resolution as well. There are at this time 147 different variables in the ASP output, including quality flags and processing information. ASPs are available to the IBM and NCAR teams, as well as any other interested user, at ftp://ftp.ssec.wisc.edu/clavr/goes_west/1kmprocessed/ and ftp://ftp.ssec.wisc.edu/clavr/goes_east/1kmprocessed/. The ASP files are available on ftp within 8-21 min after the last scan line of the image is acquired. A few of the ASPs are displayed in Google Earth format at http://cimss.ssec.wisc.edu/clavr2/google_earth/goes_west_kml1km/ and http://cimss.ssec.wisc.edu/clavr2/google_earth/goes_east_kml1km/. There is also a rolling 24-hour view of the cloud mask and GHI at http://cimss.ssec.wisc.edu/clavrx/quicklook/quicklook_main.html, also shown in Figure 12.

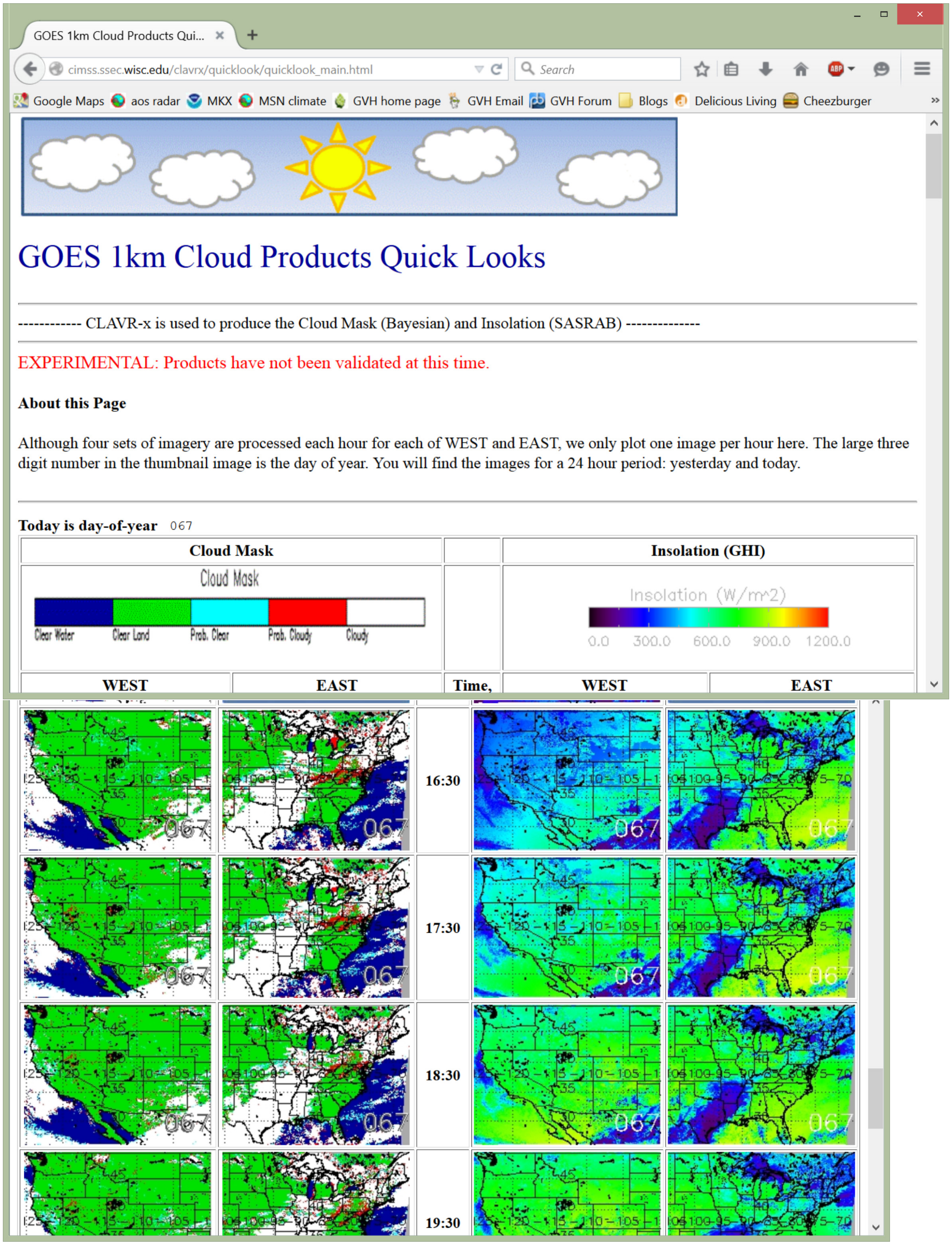

Figure 12 A view of two portions of the rolling 24 hour quick look for the Advanced Satellite Products, showing hourly cloud mask and global horizontal irradiance. Sections of the full web page have been omitted.

A document titled “User’s Guide for 1km Cloud Products Derived from GOES Imager Data using CLAVR-x” was delivered to NCAR and IBM team users. This document discusses the basics of the source imagery, the process by which it is turned into Advanced Satellite Products, and considerations users should make when using the data. Validation of selected variables from the older 4km version of the products was also included (samples in 13).

Sky Condition	Agreement
clouds/clear	85%
clear	90%
partly cloudy	41%
cloudy	92%

Site	R^2
All	0.75

Figure 13: Two sets of statistics for the 4km cloud products. On the left is the agreement for sky condition of the variable cloud_fraction versus percent cloud cover from Total Sky Imager at SURFRAD sites. Binary and ternary classifications have separate statistics. On the right, the R2 of cloud_fraction vs TSI percent cloud cover. Statistics are taken from Users Guide for 1km Cloud Products Derived from GOES Imager Data using CLAVR-x.

The actual validation process will consist of comparisons between high quality surface data and satellite-derived products. Validation will start with the permanent and mobile SURFRAD sites. Later, ISIS, ARM SGP, and an NREL site will be added. Currently being downloaded daily are the observations at SURFRAD and ISIS sites. A 15 x 15 pixel box of data for each variable in every ASP file is being extracted at the SURFRAD, ISIS, SGP, and NREL sites. These extracts are archived.

Because the surface station and the satellite are sensing the clouds, atmosphere, and surface in slightly different ways, we need to determine the optimal time vs area comparison. Previously it was determined from the 4km data, that the best agreement between the high frequency point data at SURFRAD and the instantaneous spatial data from GOES was to use a 10-minute average of data at SURFRAD and a 10-km radius average of satellite products. This optimal time/area relationship will need to be recomputed for the 1km products. The plots in Figure 14 show a 5km radius for satellite with a 10 min average of SURFRAD data. We will have the correct relationship for the 1km products by the end of Phase 1.

A web site is being built to show comparisons and statistics from daily through yearly scales. Figure 14 has two samples of the kinds of comparisons and statistics planned for the validation website. Considering the types of variables in the ASPs and the available surface observations, the following ASP variables can be validated:

- Cloud mask via surface radiometric temperature

- Cloud mask via irradiance
- Cloud fraction via total sky imager
- Cloud transmission via irradiance
- Direct/diffuse insolation via direct normal irradiance/diffuse horizontal irradiance

Statistics will include RMSE, average error, probability of correct detection, etc.

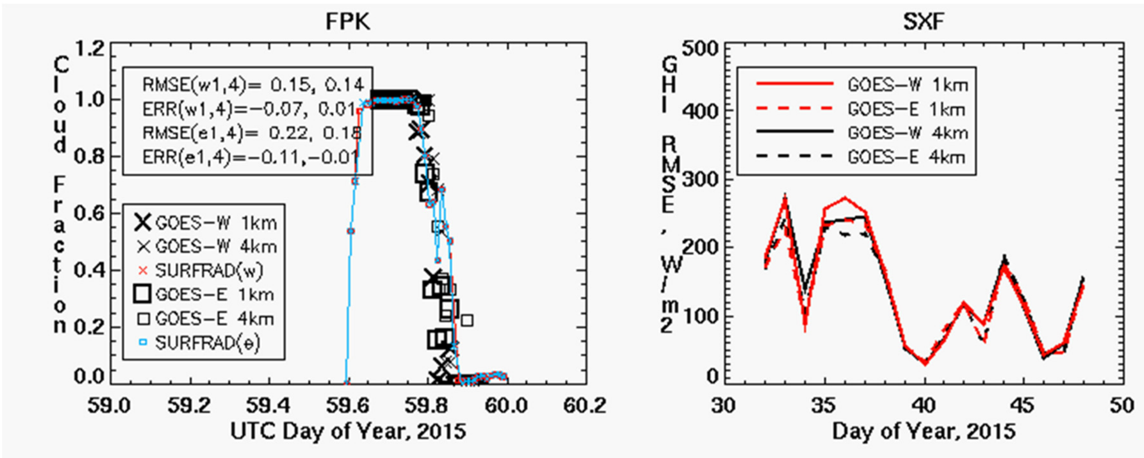

Figure 14: Two samples of data and statistics that will be available on the ASP validation web site. On the left is cloud fraction from both the 4km and 1km resolution products in comparison to data from the SURFRAD site at Fort Peck, Montana. Root mean square error and mean error statistics are shown. On the right is the root mean square error for GHI at Sioux Falls, South Dakota.

Validation efforts will be continuous and take at least one full year in order to be comprehensive. It is known from previous studies of the 4km version that satellite-based cloud product accuracy tends to be better in summer than winter for snow covered locations, and tends to be better for times and locations that have exposed and/or green vegetation during all or part of the year. This is primarily due to the benefits of a dark background allowing differentiation between a bright surface and a bright cloud. We expect the 1 km resolution ASP cloud products to show the same sort of temporal pattern, but to have a better correlation to surface observations due to the higher spatial resolution.

Ground Observations

Narrative Report and Update

B.5.1 High-quality observations sites (SURFRAD and ISIS sites)

In Phase 1, we focused on data acquisition, processing, editing, and QA/QC analysis of one year's worth of surface irradiance data from our 14-site network. This network (7 SURFRAD + 7 ISIS) collects continuous high-time resolution high-quality solar and infrared downwelling and upwelling irradiances to be used for ongoing verification and validation of short-term and day-ahead solar forecasts from NOAA's HRRR and RAP solar forecasts, CIMSS advanced satellite products, and the DOE sponsored teams. The data collected and processed amounts to more than 160 continuous, one-minute time step data streams of interest to the forecasting groups per month. This is a substantial effort for ready and direct access to the data and consultation as to its use, merits, and limitations. QA/QC data are made available nominally next day. As part of this effort, we have trained scientists to assist in our normal daily routines to ensure this daily access except on weekends.

B.6.1 Movable SURFRAD Units

The primary task for the first year was to work with our utility partners to find suitable locations at a PV or CSP utility plant to deploy our two mobile platforms one for each DOE sponsored team (IBM team and NCAR team). This effort required building, and testing of a second mobile SURFRAD platform similar to our existing mobile SURFRAD platform, which was accomplished during the summer of Phase I at our home facilities in Boulder, CO. The first mobile platform was deployed in the San Luis Valley outside Alamosa, CO at the Iberdrola San Luis Solar Farm in July, 2014. The second mobile SURFRAD platform was deployed the week of October 6 – 11, 2014 at Green Mountain Power's Energy Education Site in Rutland, VT. Figures 15A and 15B show the deployment at San Luis Valley, CO and Rutland, VT.

Figure 15A and 15B: A subset of the measurements from the mobile deployments in San Luis Valley, CO (right) and Rutland, VT (left).

Both the San Luis Valley in Colorado site and the Rutland VT site are routinely pulling in the data every 15 minutes back to our home server. The data are processed, plotted, and viewed daily. Automated routines are working to provide data in real-time to the partners via our ftp site (ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/realtime/rut and ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/realtime/slv). Figure 16 shows an example of our plots for viewing our data next day. Several diagnostics are plotted as the checks to the system. Data are accessed next day and run through our QA/QC routines next day and pushed to our web-site (ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/Alamosa_CO and ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/Rutland_VT). This is performed visually in-person and is a necessary step for quality data. We are in the process of investigating implementation of another QA/QC routines that will assist in the automation of this effort (Long et al., 2008).

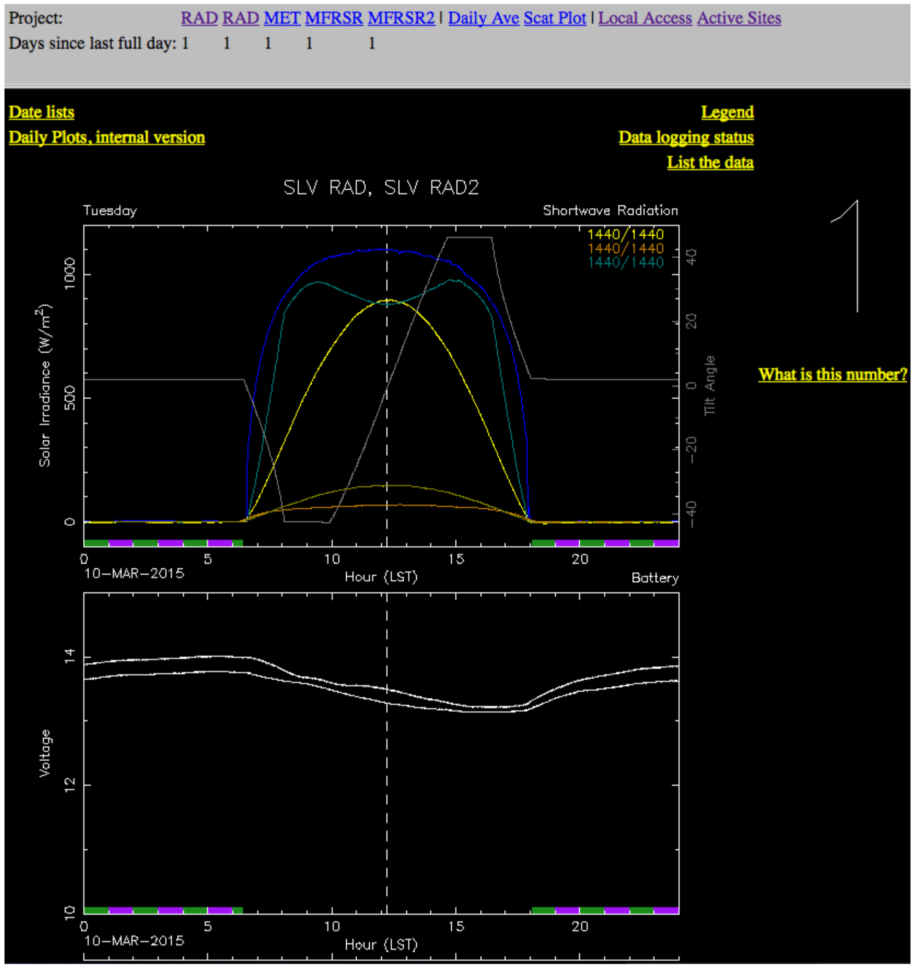

Figure 16: Daily diagnostic plots for radiation measurements at the mobile sites.

New deployments always have unplanned challenges. We incorporated at the start of the campaign visual daily plots and checks to discover issues as early as possible. These challenges were dealt with as rapidly as possible to reduce any loss of data and issues with instrumentation should be significantly reduced as the campaign proceeds. The Rutland site fulfilled many of the site requirements including available power, near-by personnel for weekly maintenance and instrument operationally problems. The site was not the most ideal for field-of-view with obstructions due to trees, the PV panels, buildings that limits the data during the winter months when the sun is low. The brutal winters there this year have added additional challenges with freezing of the TSI mirror and failure of the ventilators. The Green Mountain Team has been very helpful in addressing issues as they have arisen. These included realigning the tilt radiometer for plane-of-array measurements. We sent written and pictorial instructions and they carefully followed the procedures. We also had two failures of ventilators at the site and we upgraded the internal fan to accommodate the harsh conditions. The San Luis

Valley site also provided a few challenges. During October and November they were performing maintenance that required the power outages. During the re-boot of power the Raven communications were not coming back on even with our back up power. Even with long nights, they would revisit the site to reboot our systems. We redesigned the power back-up and the SLV team implemented the change. No radiation data was lost during the outages except for several days of image data. We also visited the San Luis Valley site to make several improvements at the site including adding a ventilator to the tilt radiometer and diagnosing a short-circuit in pyranometer on the tower that was missing data intermittently.

B.7. Real-Time SURFRAD Measurements

Improvements to the data acquisition and communications hardware were planned for half of the sites in the first year. During meetings with our partners, we realized the need to have the SURFRAD and ISIS sites communications updated on an accelerated schedule. During this first year, we were able to visit all fourteen SURFRAD and ISIS sites to upgrade data-logging systems and communications to provide near real-time radiation measurements. Instead of a 2 year schedule this task was accomplished in 8 months. This task will assist our partners to achieve their goals for validation of their model forecasting components that provide short to day-ahead solar forecasts. This was a considerable effort to visit all 14 sites and involved extending the usual yearly visits to install the components. Travel costs were leveraged using NOAA base funds by combining the upgrades with scheduled annual visits. The real-time data for the permanent SURFRAD sites is available here (ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/realtime/). The data are updated every 15 minutes. This data has minimal QA/QC, the next day further QA/QC protocols are performed and the data is moved to the archive. To assist in this project, we trained several additional personnel on the visual evaluation of the data to ensure more timely delivery of the data during this project.

B.7.1 SURFRAD and ISIS data products

B.7.1.1 Upcoming challenges for the fourth quarter, we have tasks to purchase and deploy new pyrheliometers for measuring direct normal irradiance at 3 SURFRAD sites. We have investigated available products and evaluated their specifications. The instruments have been delivered. But deployment of the first three instruments will likely be delayed into the next phase of the project (year 2). The new instruments have the ability to record temperature, which will require additional changes to the infrastructure. The instruments will be calibrated and necessary cabling built for their deployment in quarter four of the first year. We will need to address changes in the automatic data processing routines to ensure continuity in data delivery prior to deploying the instruments. We expect to deploy these three instruments during Q1-Q2 of year 2.

B.7.1.2. In Q3, we made the cloud image data available to the two DOE sponsored teams available in real-time. In addition, we reprocessed the cloud fraction calculations. We needed a period of clear-skies as well as cloudy periods to set the parameters on the TSI for detection of clear blue skies, opaque and thin. The images were then reprocessed and put our ftp site for collaboration with the NOAA CIMSS group. In Q4 we will develop and provide aerosol optical depth at the mobile sites.

B.7.1.3. In Phase I, we began efforts to acquire the HRRR, RAP, and Satellite data to optimize and facilitate the transfer of large volumes of data by working with colleagues at NOAA. This effort is on-going. In Phase II, we will temporally and spatially average the SURFRAD data for comparisons with solar forecasts.

B.7.1.4. ISIS data was previously provided at 3 minute time steps. We changed the time-step for all the sites to 1-min data including changes to the processing codes per our designated tasks. This was changed over the beginning of January, 2015.

B.7.1.5 We were to provide data recovery rates for the SURFRAD and ISIS sites. These data rates were calculated for the calendar year for the permanent sites. For the mobile sites we calculate the rates from the start date thru January, 2015. These statistics are available on request.

B.7.1.6 Most data analysis and data products are scheduled for Phase II and Phase III. We will be developing routines and procedures to provide ancillary products as time permits, e.g. spectral solar irradiance, spectral albedo, cloud optical depth.

Conclusions

Modeling

Phase I of SFIP provided the first opportunity for NOAA to investigate the performance of its rapidly updating modeling systems in the area of solar radiation forecasts. The most important capability enabling this was the new verification based on observations from the high-quality SURFRAD/ISIS network. Examining this verification in realtime during the summer of 2014 revealed the high bias in global horizontal irradiance (GHI) that the RAP and the HRRR were then suffering from. This provided us with a target to work towards in our data assimilation and modeling development (i.e., reducing the high GHI bias).

Based on this verification, we set out to improve the various data assimilation and model components which have an impact on the surface radiation budget. These are, of course, also closely tied to surface fluxes of heat and moisture and the forecast 2-m temperature and dewpoint values. The parent Weather Research and Forecasting (WRF) – Advanced Research WRF (ARW) version was upgraded to the latest version, and the Gridpoint Statistical Interpolation (GSI) software used for data assimilation was brought to the most recent version. We located and fixed some bugs in the non-variational cloud / hydrometeor analysis to better represent the convective environment, which will in turn result in better convective cloud cover. We also tested the assimilation of surface mesonet observations as well as radar radial velocity data.

Within WRF-ARW, we made many changes to the various physical parameterizations in the RAP and the HRRR. The radiation scheme has been upgraded to the RRTMG scheme, which accounts for aerosol loading based on a climatological dataset and also allows for interaction between the radiation and the microphysics scheme. The microphysics scheme was upgraded to the latest version of the Thompson scheme, which includes prognostic aerosols based upon a climatological dataset. Much work went into improvements in the planetary boundary layer (PBL scheme) that we use: the Mellor-Yamada-Nakanishi-Niino scheme. Developments within this scheme included allowing the mixing of cloud water and cloud ice, introducing a subgrid-scale nonconvective cloud fraction , and coupling this cloud fraction with the radiation scheme. Additional development focused on the Grell-Freitas-Olson shallow cumulus scheme, which was also coupled to the radiation to more realistically represent shallow convective clouds in the PBL. Finally, the RUC land surface model (LSM) was modified to improve surface conditions in certain soil types. Specifically, the vegetation wilting point for cropland was reduced to allow for more evapotranspiration, which results in a cooler and moister surface and a more cloud-friendly PBL.

Taken in tandem, these changes result in a significantly improved modeling system. The representation of cloud cover is better, and aerosol information is considered for the radiation, both of which result in improved surface GHI verification.

Satellite

The main goal of providing a real-time stream of advanced products (ASPs) was achieved. All images from GOES-West and –East that cover the contiguous USA are processed at the 1km (visible) resolution. Over one hundred cloud, atmosphere, and surface quantities are produced in addition to the many of the source ancillary fields used in the processing. Turn-around time is short, with the files available for download by the users from 8-21 minutes after image acquisition. No attempt has yet been made to reduce product latency. We believe it can be reduced to 10 or fewer minutes for all images by the end of Phase 1.

Validation is the most important step once ASPs are produced in order for the users to confidently use these products, whether for assimilation or validation of their forecasting efforts. Validation efforts have begun, and will be an ongoing effort in order to compare products under all seasons of the year.

Ground Observations

In Phase I, the ground-based measurement component of this project is on track and/or ahead of schedule on completing the designated tasks in the SOPA. Milestones this year include working with the DOE sponsored teams to find locations to deploy two mobile SURFRAD stations. One existing unit was deployed at a 30MW PV facility in the San Luis Valley in collaboration with Xcel and the NCAR team in August, 2014. The second unit was built and tested at our facilities in Boulder, CO and deployed near Green Mountain Power's Education Center in Rutland, VT in collaboration with Green Mountain Power and the IBM Team in October, 2014. Data processing was implemented and the radiation data from these two mobile sites have been made available on our ftp server in near real-time. We also are providing images and cloud fraction from the TSI cameras for these two mobile sites on our ftp site. Another milestone was upgrading our data acquisition and communication systems at 7 SURFRAD and 7 ISIS sites. We accelerated our schedule for these upgrades to provide timely radiation and cloud products. These upgrades allow more reliable and near-real time radiation data delivery to the DOE sponsored teams to meet their goals. This 1-min radiation data is provided on our ftp site ever 15 minutes. The data are QA/QC'd nominally next day and pushed to our ftp server. Lastly, we changed the data rate at the ISIS sites from 3 min to 1 min. There were a few challenges at the mobile sites with power outages, realignment of a tilt radiometer, and failing ventilators but the two utility teams have been a tremendous asset and assists in fixing these issues in the field often under winter harsh conditions. For the remainder of the fourth quarter, we expect to continue to meet goals, however, there will be a delay in installing the first three pyrheliometers at the site due to changes needed to the processing of the data. This delay will allow to have a seamless transition to the new instruments without any delays in the data stream.

Path Forward

Modeling

Much work remains to improve solar forecasts from the RAP and the HRRR. Future work will continue to be focused on the data assimilation and the model physics components. On the data assimilation side, the currently non-variational cloud / hydrometeor analysis will be completely redesigned in a variational approach. Experiments will also investigate ensemble approaches to this data assimilation. This will allow for a much more realistic initial condition for the model forecasts, particularly of clouds and precipitation.

On the modeling side, work will continue within many of the physics parameterizations. Specifically, the aerosol-aware microphysics scheme will be transitioned from a climatology-based aerosol dataset to a prognostic aerosol source and sink scheme. NOAA will continue to work with WRF-Solar developers and to take advantage of RAP-chem and HRRR-chem expertise to investigate the costliness of different methods for account for aerosols. Within the PBL scheme, work will continue to improve the representation of turbulent mixing in different stability situations. The subgrid cloud fraction introduced into the MYNN scheme will also be more appropriately coupled to the radiation and microphysics schemes. The GFO shallow cumulus scheme, a modified version of the MYNN scheme more appropriate for daytime mixed-layer conditions over land, and the radiation will be more closely coupled and energetic consistency improved. Improvements will also continue within the RUC LSM.

As GSD makes improvements to its experimental versions of the RAP and HRRR, these changes will in turn be transitioned into operations at NCEP, provided there are sufficient computing resources available. These rapidly updating models will continue to be valuable for solar irradiance forecasting.

Satellite

Now that a reliable, stable production of ASPs exists, the greatest emphasis in the next year is validation, exploring possible improvements and more validation. Validation needs to be done over the course of a full year, so this will be an important, on-going task in Phases 2 and 3. Validation is extremely important after any algorithm changes to make sure that improvements in one product do not cause the accuracy of other products to not suffer. All other activities will consist of fine tuning of coverage/latency/product-set in order to provide optimal utility to the IBM and NCAR teams.

By the beginning of Phase 3, the plan is that both teams will be happy with the cloud products, so that they have sufficient time to integrate the stable cloud products into their systems. Once that is achieved, both teams and NESDIS can discuss long term production of the ASPs – whether they will be done in-house by the teams, whether CIMSS will continue to produce them, or whether this is something NOAA Office of Satellite Product Operations wishes to take over. CIMSS specializes in “research to operations” — to conduct research identifying and validating new methods or data products, and working with OSPO to evaluate and transfer these to operations at OSPO.

Ground Observations

We will continue to maintain field data collection and processing along with related activities at each of the sites to ensure timely delivery of high quality radiation products. This is a substantial effort involving a half dozen people, which is partially funded by this effort with additional funding from NOAA base, and supplemental non-NOAA sources. A primary goal of the observational effort is the maintenance of the climatological record specific to the network location. We will continue to deliver near-real time radiation products and maintain the mobile sites and address concerns as they arise. We will continue to maintain field data collection and processing at our shorter term utility sites. Newer sites provide challenges and we will continue to work with the utility companies to keep the instruments operational. The operational issues due to instrumentation and weather related events have been addressed and are expected to be significantly reduced as we move into the future.

We will calibrate and build cabling for the new pyrheliometers to improve the direct beam solar irradiance (DNI) at the SURFRAD sites. The new cabling is needed for this specific instrument and to incorporate temperature measurements of the instruments. We will begin to develop and modify the processing routines to handle the additional information to ensure continuity of data delivery with the switch out at each of the sites. We expect to install pyrheliometers at 4 sites this summer/fall, which will bring us in line with our projected goals. Travel budget will be leveraged under existing programs.

We will be installing new upgraded Multi-Filter Radiometers at 4 sites this summer/fall. These instruments will have an “open” thermopile channel, which will provide total, diffuse, and direct shortwave solar irradiance. An additional MFR will be installed at these 4 sites to measuring upwelling irradiance in the same 7 channels. The two instruments (MFRSR + MFR) measuring upwelling and downwelling irradiance will enable us to measure the spectral surface albedo at the sites. This is a substantial effort, as some of the sites will need power installed at the tower and requires addressing agreements and trenching power to the towers at a few sites. These upgrades are funded under a separate grant; these upgrades in instrumentation and the additional products will be valuable for the solar forecasting community.

In the next quarter we will work on the algorithms to provide aerosol optical depth at the mobile sites. At the permanent sites, we will calculate aerosol optical depth for the end of 2013 and 2014. New instrument additions (MFRSR) at several of the sites will require modification of the processing of aerosol optical depth to account for atmospheric constituents (e.g. CH4, CO2, H20), and development of a method to retrieve this information operationally to provide aerosol optical depth in the 1625 nm channel. Also, as new MFRSR instrumentation is added to the sites this will require the algorithms to be rewritten to take into an account the improved temperature dependence for processing the aerosol optical depth. A span of data will be needed at each of the sites to develop this correction for each individual instrument.

In Phase I, we began efforts to acquire the HRRR, RAP, and satellite data working with others at NOAA to facilitate and optimize the transfer of large volumes of data. This is on-going. In Phase II, we will perform spatial and temporal averaging of the SURFRAD and ISIS data for comparisons to the HRRR, RAP, and advanced satellite products. We are working with the CIMMS group to provide cloud-fraction at the mobile sites and providing guidance on the strengths and limitations of the product.

We will address what appears to be an angular response change in the MFRSR at the SLV site by returning the instrument to the laboratory for characterization and returning to the field within 5 days to limit loss of data. During this period, we plan to install infrared radiometers at this site. Though this was not part of the original plan, these instruments will provide valuable information for NWP models to understand radiative effects and cloud formation. Also, these instruments provide valuable information for detecting clear-sky periods and for additional quality control indicators.

At the end of this project year, we will retrieve the SURFRAD mobile platforms from the San Luis Valley, CO site and the Rutland, VT site. This is an effort requiring 3 personnel for a week of preparation and a week for removal of the instruments. The NCAR team is interested in having our instrumentation operational beyond the designated year and extended through December. One mobile unit is obligated under another program but this field deployment may be delayed until 2016. Operating the mobile unit does require extra effort to maintain and process the data during this additional period, but this is a possibility and we would like to continue to provide this data stream.

References and Presentations

Presentations

1. Molling, C. et al., 2014: NOAA's Contribution to Improving Accuracy of Solar Forecasting. Sunshot Summit, Anaheim, CA, May 20. Invited Poster Presentation and Review.

2. Marquis, M., 2014: Use of Satellite Observations in Wind and Solar Forecasting and in Offshore Wind Resource Assessments, AMS Annual Meeting, Atlanta, GA, Feb. 3.

3. Marquis, M., 2013: NOAA Partnership in Solar Forecasting, Utility Variable Generation Forecasting Workshop, Salt Lake City, UT, Feb. 25. Invited Panel Presentation.

4. Benjamin, S., 2013: Components of RAP/HRRR changes related to WFIP and solar programs, Utility Variable Generation Forecasting Workshop, Salt Lake City, UT, Feb. 25. Invited Panel Presentation.

5. Benjamin, S. , 2014: NOAA Hourly Updated Weather Forecast Models for Renewable Energy, Utility Variable Generation Forecasting Workshop, Tucson, AZ, Feb. 25. Invite Panel Presentation.

6. Benjamin, S. et al, 2013: Earth System Prediction Capability Demonstration Goal #1 – Improved 1-6 Week Forecasting of Extreme Weather Related to Blocking Events – Initial Directions, AMS Annual Meeting, Austin, TX, Jan. 8.

7. Benjamin, S. et al, 2014: Time-lagged consistency in hourly updated 3-km HRRR wind ramp forecasts for 2013/2014, AMS Annual Meeting, Atlanta, GA, Feb. 3.

8. Lantz, K. Ground-based observations of solar irradiance for SFIP, A Public-Private Academic Parnership to Advance Solar Power Forecasting Workshop, NCAR, Boulder, CO, Aug. 26 – 27, 2014.

9. Michalsky, J.,Ground-based Validation of Satellite Retrievals and Forecasting of Solar Irradiance, IBM Solar Forecasting Workshop, Aug 19 – 20, 2014.

10. Benjamin, S., J. Olson, E. James, J. Kenyon, C. Alexander, J. Brown, T. Smirnova, and M.Hu, 2015: HRRR and RAP assimilation and model improvements for wind and solar energy guidance. Utility Variable-Generation Integration Group 2015 Forecasting Workshop, 18-19 Feb 2015, Denver, CO.

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